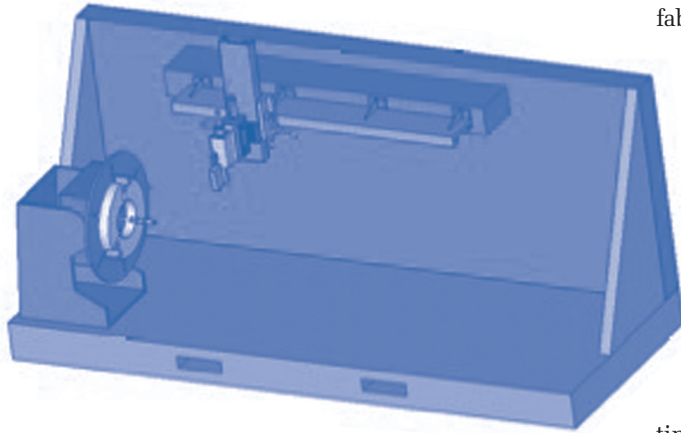


## Laser-hybrid welding of pipe spools

ARL's Laser Processing Division was recently funded by The Center for Naval Shipbuilding Technology (CNST) to develop a laser-hybrid welding workcell for fabrication of piping spools in support of the Navy's T-AKE cargo ships being built by National Steel and Shipbuilding Company (NASSCO). The spools are currently manufactured using multi-pass flux core arc welding (FCAW) techniques.



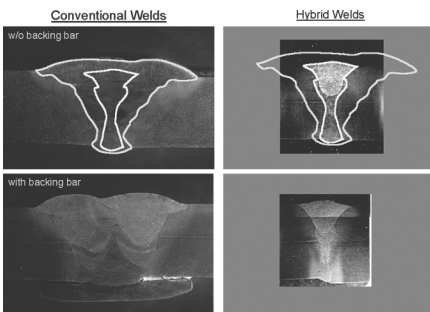
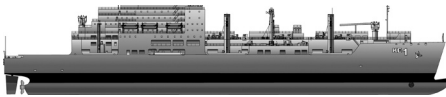
The laser-hybrid welding process combines laser beam welding with the gas metal arc welding (GMAW) process. With appropriate joint configuration and preparation, deep penetration provided by the laser and additional filler metal and heat input provided by the GMAW torch will permit single-pass butt-welding of pipes and fittings. This not only decreases weld processing time, but can be expected to reduce weld defects due to fewer starts-and-stops compared to multi-pass weld joints.

With welding time savings of 80% or more expected by replacing multi-pass FCAW joints with the single-pass laser hybrid welding joint, more than \$0.5M in annual cost savings are expected.

This workcell is to be used for joining carbon steel pipe to butt weld fittings. The diameter of pipe to be welded ranges from 4 inch NPS to 30 inch NPS, in wall thicknesses up to ½ inch. The workcell will integrate the latest off-the-shelf technology to ensure defect-free welds. For example, the welding head will employ a high-speed laser seam tracking sensor for following the joint, head manipulation, and adjustment of weld schedule in response to gap fluctuations and tack welds.

ARL and NASSCO will work together during development of the pipe welding workcell. The final project deliverable involves a 3-month "pre-production" demonstration at NASSCO's pipe welding facility using NASSCO welding personnel and production spool components. Interested parties from other shipyards will be invited to witness the pipe welding demonstrations.

For more information, contact Ted Reutzl at (814) 863-9891 <ewr101@psu.edu> or Dennis Wess at (814) 865-7063 <dbw105@psu.edu>.



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## DIRECTOR'S CORNER

### New Fiscal Year Begins

It is my sad duty to inform you of the death of an outstanding engineer who was working on several iMAST projects, and was a vital contributor to many successfully completed projects. Eric Whitney, who was the lead investigator on the RepTech Vertical Launch System Tube Repair and the CVN 21 Laser-Welded Lightweight Structure Fabrication died recently. This was not expected. He will be sorely missed.



As you read this, the new fiscal year will have started. As the year progresses, projects supporting the next generation destroyer (DDX) will be completing, projects supporting the next generation carrier will be in full swing, and projects supporting the Littoral Combat Ship should be starting. In addition, we are working with the naval shipyards, air depots and Marine Corps Logistic Bases to reduce the cost of depot maintenance under the auspices of the RepTech program. I am encouraged by the

cooperation I've experienced from the shipyards. Teams are focused on delivering the best possible product at the best value to the Navy. I believe our success at implementing new technologies is dependent on constant communication between the defense contractor, the technical authorities, and the investigators.

The feature article describes the spray metal forming process. This is an encouraging technology for the manufacture of alloys with improved properties that can't be produced in standard procedures. With the focus on reducing weight while maintaining performance, the need for new materials is great.

The Defense Manufacturing Conference will be held in Orlando from November 28th to December 1st. There will be six presenters from the Applied Research Laboratory briefing projects and technologies during the technical sessions. I encourage you to attend and participate in the technical sessions.

*Bob Cook*



**MATERIALS  
PROCESSING  
TECHNOLOGIES**



**MECHANICAL DRIVE  
TRANSMISSION  
TECHNOLOGIES**



**LASER  
PROCESSING  
TECHNOLOGIES**



**COMPLEX SYSTEMS  
MONITORING  
TECHNOLOGIES**



**ADVANCED COMPOSITES  
MATERIALS  
TECHNOLOGIES**



**NAVY/MARINE  
CORPS REPAIR  
TECHNOLOGIES**



**MANUFACTURING  
SYSTEMS  
TECHNOLOGIES**

# High Strength Aluminum Alloys Produced By Spray Metal Forming

by Timothy J. Eden, Ph.D.

World events have emphasized the importance of developing light weight, high-performance materials, especially those that can be used in armor and blast resistance structures. Recent work at Penn State's Applied Research Laboratory has produced some high-performance aluminum alloys. These materials, produced by Spray Metal Forming, have superior properties which have shown potential for use in military vehicles to provide light-weight ballistic protection.

## BACKGROUND

Rapid solidification processes such as spray metal forming offer some distinct advantages over conventional ingot metallurgy processing. Superior properties due to fine grain sizes; a fine, homogeneous distribution of second phase precipitates; and the absence of macro-segregation result from cooling rates on the order of  $10^6$  to  $10^7$  K/s<sup>1</sup>. Although the cooling rate in spray metal forming is not as high as other rapid solidification processes, ( $10^3$  to  $10^5$  K/s), the cooling rate is sufficient to produce a fine microstructure with a high volume fraction of strengthening components<sup>2</sup>.

The highest cooling rates are obtained through gas atomization and ribbon casting or melt spinning. For rapid solidification processes that produce metal powders, additional processing steps are required. The aluminum alloy powders are atomized in the air to form a thin layer of oxide, which makes the powders safer to

handle. Subsequently, these metal powders must be sieved, classified, and consolidated in an inert atmosphere. Spray metal forming offers the distinct advantage of skipping these intermediate steps, in a single operation, by atomizing and collecting the spray in the form of a billet. Also, the elimination of powder handling reduces oxide content and enhances ductility.

The spray metal forming process is a single integrated rapid solidification technology for producing semi-finished tubes, billets, plates and simple forms in a single integrated operation. The most widely used spray metal process is patented by Osprey

Metals Ltd, Neath, Wales<sup>1</sup>. Spray forming involves converting a molten metal stream into a spray of droplets by high-pressure gas atomization (Figure 1). The droplets cool rapidly in flight and ideally arrive at a collector plate with just enough liquid content to spread and completely wet the surface. The metal then solidifies in to an almost fully dense preform with a very fine, uniform microstructure.

The spray forming plant currently at ARL/Penn State, shown in Figure 2, is the only spray forming plant in North America specifically designed for aluminum alloys. Metal is placed in a crucible and heated to the desired

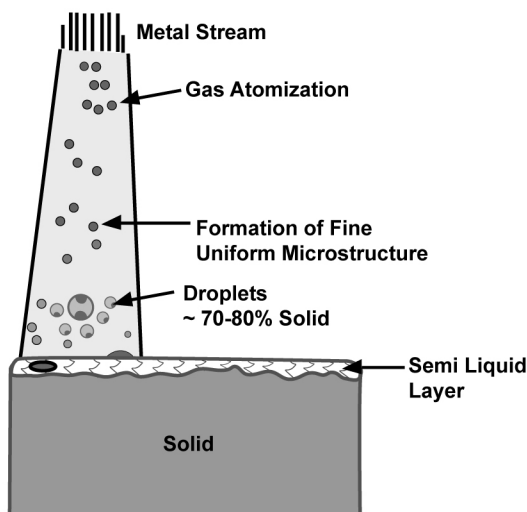


Figure 1. The atomization and deposition process for spray metal forming.

## PROFILE

Timothy J. Eden is a research associate and acting head of the materials processing department in ARL Penn State's Materials and Manufacturing Office. Dr. Eden received a B.S. in mechanical engineering from the University of Utah, and an M.S. and Ph.D. in mechanical engineering from The Pennsylvania State University.

Dr. Eden's research interests include high velocity particle consolidation, spray metal forming, multiphase heat transfer and fluid flow, process control and optimization, ceramics processing, and thermodynamics. He can be reached at (814) 865-5880, or by e-mail at <tje1@psu.edu>.



temperature under an inert atmosphere. The spray chamber is purged with nitrogen. The process is started by lifting a stopper rod allowing a metal stream to flow through the nozzle in the bottom of the crucible. High pressure nitrogen jets at near sonic velocity atomize the molten stream and carry it

toward the collector plate. The collect plate is placed on a ram that rotates and withdraws to maintain a constant spray height to ensure that the billet is uniform and that the composition and microstructure are uniform through out the entire billet. Process variables are closely controlled to produce the

desired cooling rate and microstructure. These include the gas-to-metal ratio (G/M), commonly defined as cubic meters of gas per kilogram of metal, the pour temperature, spray height or metal droplet flight distance, and metal flowrate.

## ARL/PENN STATE FACILITIES

The Penn State spray metal forming facility is a research scale plant that is capable of producing billets, plates and tubes. The melt capacity is 145 lbs of aluminum. Billets with diameters from 7 to 9 inches can be produced with lengths up to 16 inches. Plates can be produced that are 6 inches wide by 12 inches long with thickness up to 0.8 inches. A powder feeder may be used to inject particulate reinforcement into the gas stream near the point of atomization to form a metal matrix composite with uniform distribution of the injected particulate.

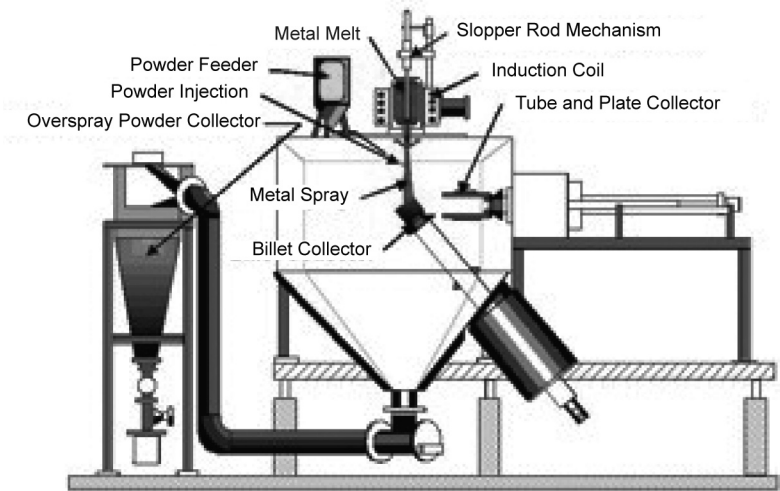


Figure 2. Schematic of the spray metal forming plant at the Applied Research Laboratory.

Table 1. Summary of High Strength Aluminum Alloys										
Alloy Number	% Weight Composition							Yield Strength @ 0.2% Offset (ksi)	Ultimate Tensile Stress (ksi)	% Elongation at Fracture
	Zn	Mg	Cu	Mn	Cr	Zr	Mg+Cu+Zn/6*			
Spray Formed Alloys										
Pech- 1 <sup>3</sup>	12.0	3.0	1.0	0.25	0.20	0.20	6	114.6	117.5	8.0
Pech- 4 <sup>3</sup>	9.0	3.5	1.2	0.25	0.15	0.25	6.2	113.9	116.8	9.0
Pech- 8 <sup>3</sup>	12.1	2.9	1.0	0.20	0.20	0.15	5.9	114.7	115.0	0.5
Eura- 2 <sup>4</sup>	12.0	3.0	0.9	0.19	0.12	0.20	5.9	117.3	118.6	6.7
Eura- 3 <sup>4</sup>	12.5	2.8	1.3	0.20	0.12	0.20	6.2	113.3	115.3	7.3
Eura- 5 <sup>4</sup>	10.8	2.9	1.0	0.10	0.11	0.27	5.7	104.1	112.7	8.2
SS70 <sup>5</sup>	11.5	2.64	1.16	0	< 0.01	0.26	5.7	109.5	116.5	5.0
N707 <sup>5</sup>	10.9	2.16	1.01	0	< 0.01	0.22	5.0	103.1	107.3	5.0
N707 <sup>6</sup>	10.46	2.27	1.01	0	0	0.31	5.0	95.2	100.4	9.5
Conventionally Processed 7XXX										
7039- <sup>7</sup> T61	3.5-4.5	2.3-3.3	<0.1	.1-.4	.15-.25	<0.1 Ti	3.6	47.9	58.0	13.0
7068 <sup>8</sup>	7.3-8.3	2.2-3.0	1.6-2.4	<0.10	<0.05	0.05-0.15	5.9	99.1	103.0	9.0
7050- <sup>8</sup> T6	5.7-6.7	1.9-2.6	2-2.6	<0.1	<0.04	0.08-0.15	5.1	71.0	80.0	11.0
7075 <sup>5</sup>	5.6	2.5	1.6	0.3	0.2	0	5.0	73.0	83.0	11.0
* For Spray Formed Alloys 5.5≤Mg+Cu+Zn/66.5 (US Patent #4,995,920)										

Table 1.

The Metals and Ceramics Processing Department has facilities to extrude 1 inch diameter slugs from spray formed billets into 0.3 inch diameter rods. Extrusions can be performed at temperatures up to 970°F and at loads approaching 80 tons. Characterization capabilities include optical metallography, hardness, tensile, dynamic modulus, dilatometer (coefficient of thermal expansion) tests; scanning, backscatter, and transmission electron microscopy; electron microprobe; and x-ray diffraction. Heat treating furnaces are also available within the department. When necessary, these tests can be preformed within a week to rapidly characterize new materials.

Many different aluminum alloys and SiC-particulate reinforced aluminum Metal Matrix Composites (MMC) have been processed at Penn State. They include conventional alloys in the 2XXX, 3XXX, 5XXX, 6XXX, and 7XXX series; high-temperatures and high-strength alloys; and high silicon content alloys. This paper presents work performed with high strength aluminum alloy, specifically N707. These alloys are considered 7XXX series and have been especially formulated to take advantage of the spray forming



Figure 3. N707 billet in the as sprayed condition before machining.

Table 2. Mechanical Properties for Spray Formed N707				
Alloy	Yield Strength @ 0.2% Offset (ksi)	Ultimate Tensile Stress (ksi)	Youngs Modulus (Msi)	Elongation at Fracture %
N707 <sup>5</sup>	103.1	107.3		5.0
N707 <sup>6</sup>	95.2	100.4	10.1	9.5

Table 2.

process. The higher cooling rate of spray forming makes it possible to process alloys with zinc contents as high as 12%, while maintaining good ductility. The partial chemistries and properties for several different alloys are presented in Table 1. The alloys Pech 1, Pech 4, N707, 7050, 7075, and 7068 have been produced at ARL Penn State.

## ULTRA-HIGH STRENGTH ALUMINUM ALLOY

The objective of a recent program conducted at Penn State's Applied Research Laboratory was to produce plates that were 12 inches x 12 inches x 1 inch of high strength aluminum alloy. The spray formed alloy N707 was selected for processing. Six billets of N707 alloys, weighing between 53 and 61 lbs, were produced in the spray forming facility at ARL Penn State. A typical billet is shown in Figure 3. The billets were then machined to an eight inch diameter cylinder for extrusion. The billets were heated and extruded through a 1.6 inch x 6.7 inch rectangular die at Universal Alloys Corporation, Anaheim, CA. An extrusion is shown in Figure 4. The extrusions were machined to ensure uniform dimensions and cut into 12 inch lengths for rolling. The 12 inch x 1.8 inch x 6.7 inch was hot rolled at Manufacturing Science Corporation,



Figure 4. Extruded N707 plate that is 27 inch x 6.7 inch x 1.9 inch.

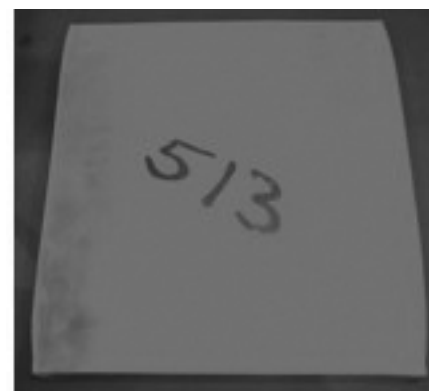


Figure 5. Extruded and rolled N707 plate that is 12 inch x 12 inch x 1 inch.

Oak Ridge TN, to 12 inch x 12 inch x 1 inch (Figure 5). Samples from the extrusions were used to develop the heat treatment needed for peak aging. The plates were then heat treated. Samples were taken from the rolled plates for analysis and property measurement. Tensile tests were conducted according to ASTM E8-04 at Westmoreland Mechanical Testing and Research, Inc. Youngstown, PA. The results of the mechanical property testing are presented in Table 2, along with the published results from tests conducted by Salamci<sup>5</sup>. The material tested by Salamci was extruded. The tensile properties were determined from samples taken from the extruded and rolled plates. The tensile and yield strengths of the ARL N707 are about 10% lower than the values reported by Salamci. There is, however, a marked improvement in the % elongation. The difference in properties can be attributed to process variations; i.e. extrusion ratio, extrusion versus extrusion and rolling, compositional differences. These results show that the

material can be processed in different way and still yield excellent mechanical properties.

Ballistic tests were performed on the 12 inch x 12 inch x 1 inch plates by the Army Research Laboratory. Results showed that the high strength N707 materials had excellent potential for armor applications. The formability of the alloy will allow it to be used in many different configurations. It can be rolled into plate for armor and hull applications, extruded for structural components, and forged to make high strength, lightweight net-shaped components.

An additional concept for taking advantage higher strength aluminum is to produce structural components that also offer increased blast resistance. A methodology was developed at the Applied Research Laboratory to design and model the performance of such components. Finite element analysis was used to develop models to predict the behavior of the structure exposed to a blast wave. As a proof of concept, an extrusion die was designed and fabricated (Figure 6). Al-6061 was extruded as shown in Figure 7. Design and fabrication techniques have been developed to produced structures that can meet a wide range of structural, blast, volume and weight constraints. The voids can be filled with a number of different materials such as metal foam or ballistic resistant foams to improve performance.

## CONCLUSION

The Metals and Ceramic Processing Department has successfully applied spray forming techniques to produce high strength aluminum alloys that maintain durable properties when rolled into thick plates. The N707 alloy has shown excellent potential for ballistic resistance. In addition, a design methodology has been developed to produce structures that offer increased blast resistance compared to solid structures of the same dimensions. These are part of an

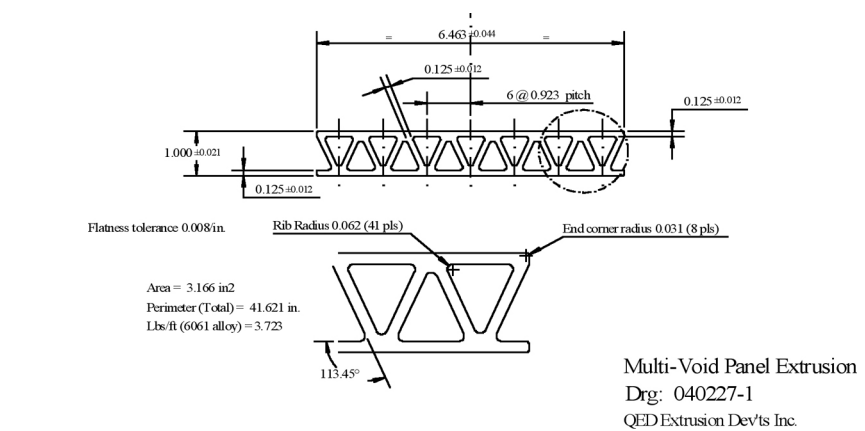


Figure 6. Computer rendering of the fixture design, showing rotation to weld the opposite side of the panel.

ongoing research thrust at the Applied Research Laboratory to develop high performance, light weight materials and structures that have improved blast and ballistic resistance. The design and fabrication methods developed can be extended to other materials such as composites, titanium and steel.

## ACKNOWLEDGEMENT

The author wishes to express appreciation for support of this effort by the Institute for Manufacturing and Sustainment Technologies (iMAST), a U.S. Navy Center of Excellence sponsored under contract by the Navy Manufacturing Technology Program, Office of Naval Research. Any opinions, findings, conclusions and recommendations expressed in this material are those of the author and do not necessarily reflect the views of the U.S. Navy.

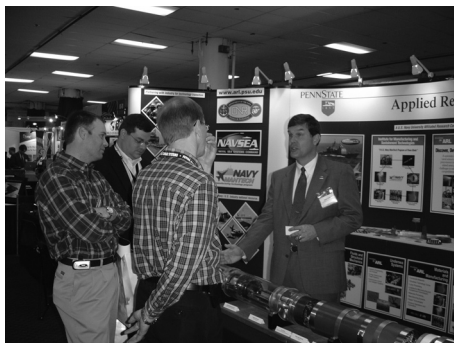
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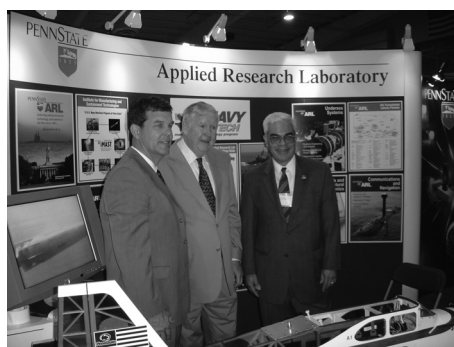


Figure 7. Al-6061 extrusion for light weight blast resistant structure.

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iMAST Director, Bob Cook, answers questions for visitors stopping by ARL-iMAST exhibit booth.



iMAST Director, Bob Cook, shares moment with Congressman John Murtha (center) and ARL Penn State Director, Dr. Edward Liszka, at ARMTech Showcase in Kittanning, PA (western Pennsylvania).



ICAF manufacturing industry study group members pause for a photo in front of ARL Penn State's Applied Science Building.

### Navy League Expo

The annual Navy League Sea-Air-Space Exposition held in Washington, D.C. once again provided an opportunity for iMAST to share program information with Navy and industry leaders. Significant industry participation drew large numbers of Navy and Marine Corps officials. This year's theme "Ensuring Global Access" provided an opportunity to highlight one of the most important missions of the U.S. Navy. Our ability to operate from the maritime domain allows us to project power around the globe without a permission slip. Since 1902, the Navy League has been educating Americans on the need for sea power, on and under the sea, in the air, and out in space. The annual exposition provides a forum for the sea service professionals and the defense industry to come together. ARL Penn State is proud to be a corporate member of the Navy League.

### ARMTech Showcase for Commerce

Members of iMAST once again participated in the annual Armstrong County Technology Showcase held in Kittanning, PA. Participation in events like this remain an essential part of the technology transition process which Navy ManTech requires. As with any technology, the ability to transfer and implement that technology depends on finding appropriate industry partners. Events like ARMTech provide an opportunity for government, academia, and industry to meet in order to identify and exchange new ideas for technical innovation. This, in turn, provides a vehicle which can enhance the production and performance of DoD-related systems, at an affordable cost to U.S. taxpayers.

### ONR Naval-Industry R&D Conference

The Ronald Reagan Building and International Trade Center in downtown Washington, D.C. once again provided an impressive setting for Navy ManTech representatives discuss program efforts. Sponsored by the Office of Naval Research, the conference has been established to leverage dialog between government, industry, academia, and the U.S. Navy and Marine Corps. A series of interactive breakout sessions provided forums to seriously discuss the challenges facing the defense industrial base. Next year's annual conference will be at a date and location to be announced. For further information, check our future calendar of events for more information as it becomes available.

### ICAF Visits iMAST

Student and staff members of the Industrial College of the Armed Forces (ICAF) manufacturing industry study group recently visited ARL as part of a capabilities assessment tour. ICAF members were provided overview briefings on the Applied Research Lab and our iMAST U.S. Navy Manufacturing Technology program. Many of the future leaders who will direct acquisition, industrial preparedness, and S&T efforts, for the Navy and Marine Corps, matriculate through ICAF. Tours were also conducted throughout the lab to include manufacturing-related issues being addressed lab-wide. For more information about ICAF, visit their web site at <http://www.ndu.edu/icaf/>



## CALENDAR OF EVENTS

### 2005

<b>1–3 Nov.</b>	ICALEO '05		Miami, FL
<b>8–9 Nov.</b>	Materials & Manufacturing Advisory Board (Force Protection/National Security)		State College, PA
<b>15 Nov.</b>	Laser Processing Industrial Advisory Board Meeting		State College, PA
<b>Nov. 28–1 Dec.</b>	Defense Manufacturing Conference 2005	★★★★★★ visit the iMAST booth	Orlando, FL

### 2006

<b>11–14 Jan.</b>	Surface Navy Association Symposium	★★★★★★ visit the iMAST booth	Crystal City, VA
<b>5–7 Feb.</b>	Tactical Wheeled Vehicles Conference		Monterey, CA
<b>4–6 Apr.</b>	Navy League Sea-Air-Space Expo	★★★★★★ visit the iMAST booth	Washington, D.C.
<b>9–11 May</b>	American Helicopter Society Forum 62	★★★★★★ visit the iMAST booth	Phoenix, AZ
<b>26–29 Jun.</b>	U.S. Coast Guard Innovation Expo		Tampa, FL
<b>Jun. TBA</b>	Johnstown Showcase for Commerce	★★★★★★ visit the iMAST booth	Johnstown, PA
<b>Jul. TBA</b>	ONR Naval-Industry R&D Conference	★★★★★★ visit the iMAST booth	Washington, D.C.
<b>Aug. TBA</b>	ARMTech Showcase for Commerce	★★★★★★ visit the iMAST booth	Kittanning, PA
<b>12–14 Sep.</b>	Marine Corps League Expo	★★★★★★ visit the iMAST booth	Quantico, VA
<b>9–11 Oct.</b>	AUSA Expo		Washington, D.C.
<b>23–26 Oct.</b>	Expeditionary Warfare Conference		Panama City, FL
<b>23–26 Oct.</b>	DoD Maintenance Conference		Reno, NV
<b>4–7 Dec.</b>	Defense Manufacturing Conference	★★★★★★ visit the iMAST booth	TBA

### Quotable

*“We’re going to have to press the comfort zone of technologist, because they’re going to have to think a lot harder and differently, and industry is going to be pressed in that they really have to come up with some new concepts.”*  
*—Michael Andrews, Chief Scientist and Deputy Assistant Secretary of the Army for Research and Technology*

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